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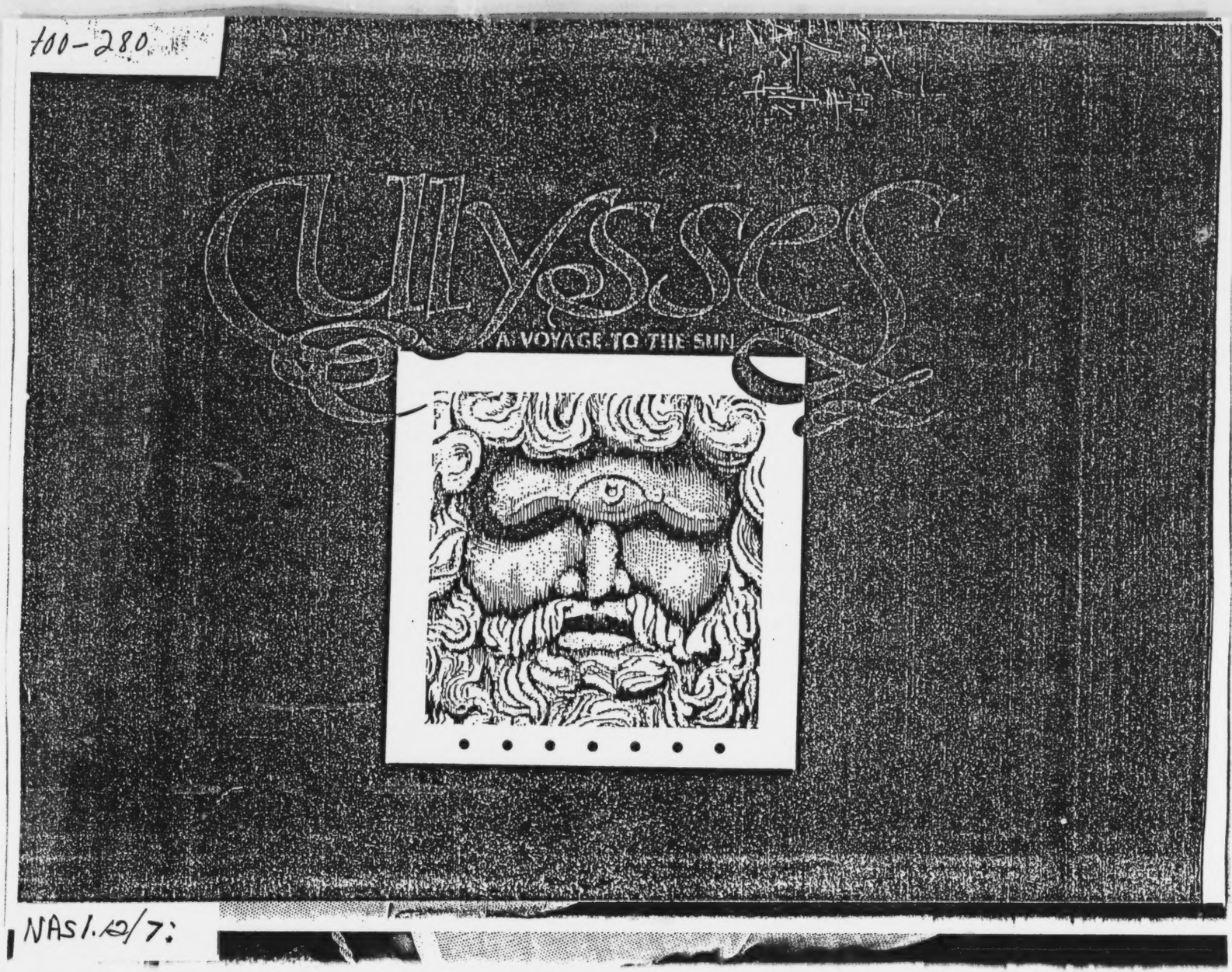

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Right: Egypt's Pharaoh Akhenaten and his wife Nefertiti established the worship of a single God — the sun disk.

Facing page: The intricate form of a solar eruption, photographed by Skylab, traces out twisting magnetic field lines as they are torn from their roots in the chromosphere. The eruption began as a low-lying prominence that here has soared upward 600,000 kilometers above the surface of the Sun.

Introduction

Astrophysicists study the Sun because it is the only star that is close enough to study in detail. Physicists probe the Sun because it is a marvelous laboratory where they can observe unique conditions of temperature, density, fluid motions and magnetic fields. The goal of atmospheric physicists and climatologists is to understand the Sun's effects on the Earth. All those scientists can trace the lineage of their endeavors back more than three centuries to the year 1610 when Galileo aimed his new telescope at the Sun and saw for the first time that our nearest star rotates and that its face is speckled with sunspots. While our knowledge has grown a thousandfold since Galileo's time, it was the advent of space exploration in 1958 that accelerated our understanding of the Sun. Suddenly scientists could send their instruments above Earth's atmosphere, which clouds and distorts their viewing. The first spacecraft to explore another planet, Mariner 2, was sent to Venus in 1962 and along the way it confirmed the existence of the solar wind, a plasma that streams from the Sun. Mariner 2 added new, hard data to our understanding of the phenomenon. For more than two and one-half decades scientists have mounted instruments on spacecraft to study the Sun and the solar wind—and the entire heliosphere, the region of space that is dominated by the Sun. But none of those machines could fly above the plane of the ecliptic—the plane in which Earth orbits the Sun. To fly out of the ecliptic, to overcome the energy imparted to a spacecraft by the motion of Earth around the Sun, requires more rocket power than is available. Therefore scientists have been unable to study two subjects of great importance to them: the entire set of interactions—of solar wind, magnetic fields and cosmic rays—that take place at the Sun's poles; and a full understanding of the physics of the Sun. To fly above the poles of the Sun is the reason for the mission called Ulysses.

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The Ulysses Mission

Ulysses is an international project of the National Aeronautics and Space Administration and the European Space Agency. A space shuttle and a Centaur G-prime upper stage will launch the Ulysses spacecraft, which is provided by the European partners. Ulysses will explore the Sun and the heliosphere and regions that are unexplored—above the Sun's north and south poles.

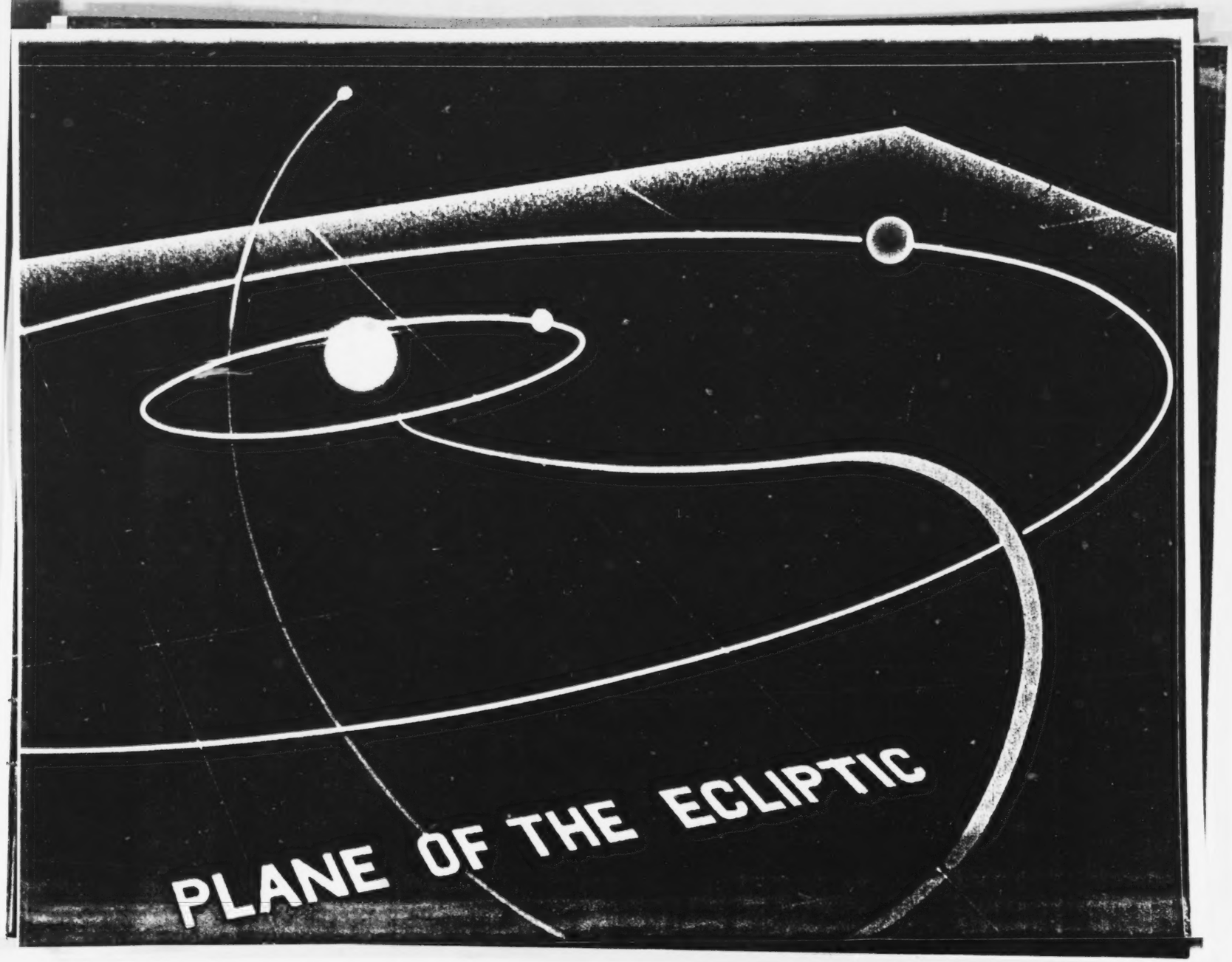
But since launch vehicles cannot propel modern spacecraft up and out of the ecliptic, the trick is to find some other way to bend the flight path, and the solution is the immense gravity of the planet Jupiter. By aiming at just the right point near Jupiter to make use of its gravity field, Ulysses will get what amounts to a free ride on a natural launch vehicle. Therefore Ulysses will be sent to Jupiter and will arrive there fourteen months after departure from Earth. Jupiter's gravity will send the spacecraft plunging back inward toward the Sun's south pole.

During the mission Ulysses' nine scientific instruments—the products of U.S. and European scientific laboratories—will collect information about the Sun's poles, the heliosphere and the cosmic rays that stream into the solar system from among the stars of the Milky Way.

Although Ulysses will study those subjects during the entire flight, the most intense scientific activity will begin as Ulysses approaches the Sun; it will reach 70 degrees south solar latitude on its climb over the pole and the first encounter will begin. At that latitude and more than twice the Earth's distance from the Sun, the scientific instruments will sample a region of the heliosphere that has never been studied before.

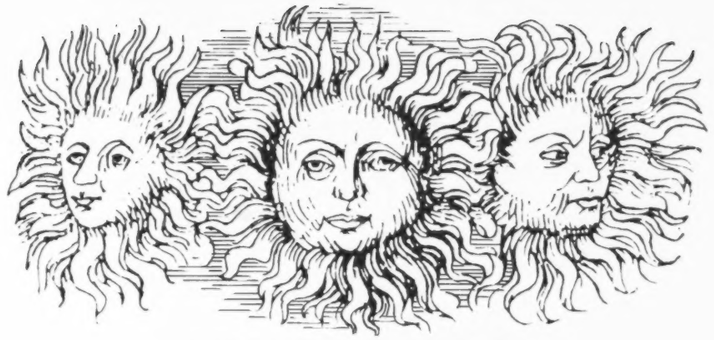
Left: Atop its Centaur upper stage, Ulysses moves away from the shuttle during the launch phase.

Facing page: The flight path that Ulysses will take from Earth to Jupiter and then over the poles of the Sun.


PLANE OF THE ECLIPTIC

The Ulysses spacecraft, responding to the Sun's gravity field, will arc toward the solar equator and cross it at one astronomical unit (the distance from the Sun to Earth). It will then climb on toward the north pole. The intense scientific interest will peak again when Ulysses crosses 70 degrees solar latitude—this time in the northern hemisphere.

At last, almost five years after the launch of Ulysses, the primary mission will come to an end when the spacecraft dips below 70 degrees north solar latitude. The mission will have detected and measured particles inbound from the Milky Way, explored the heliosphere at all latitudes, and measured phenomena above both poles of the Sun.



ULYSSES MISSION TIMETABLE

Event	Elapsed Time After Launch
Launch	0
Centaur deployment and firing	Day 1
Ulysses checkout	Day 2–9
Jupiter encounter	Month 14
First solar passage	Month 42
Cross solar equator	Month 49
Second solar passage	Month 51
End of mission	Month 58

Locations of the experiments on board the Ulysses spacecraft.

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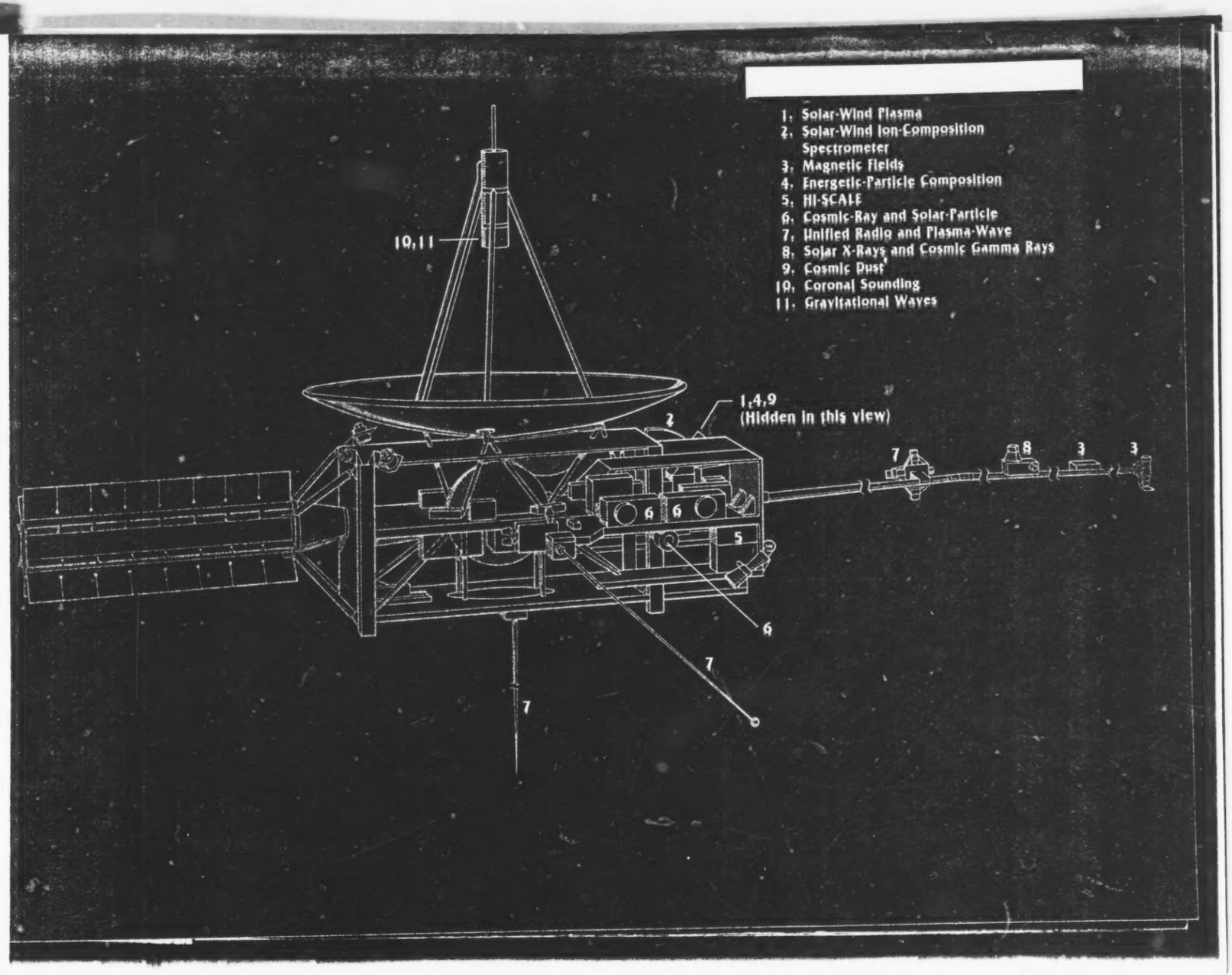
1. Solar-Wind Plasma
2. Solar-Wind Ion-Composition Spectrometer
3. Magnetic Fields
4. Energetic-Particle Composition
5. HI-SCALE
6. Cosmic-Ray and Solar-Particle
7. Unified Radio and Plasma-Wave
8. Solar X-Rays and Cosmic Gamma Rays
9. Cosmic Dust
10. Coronal Sounding
11. Gravitational Waves
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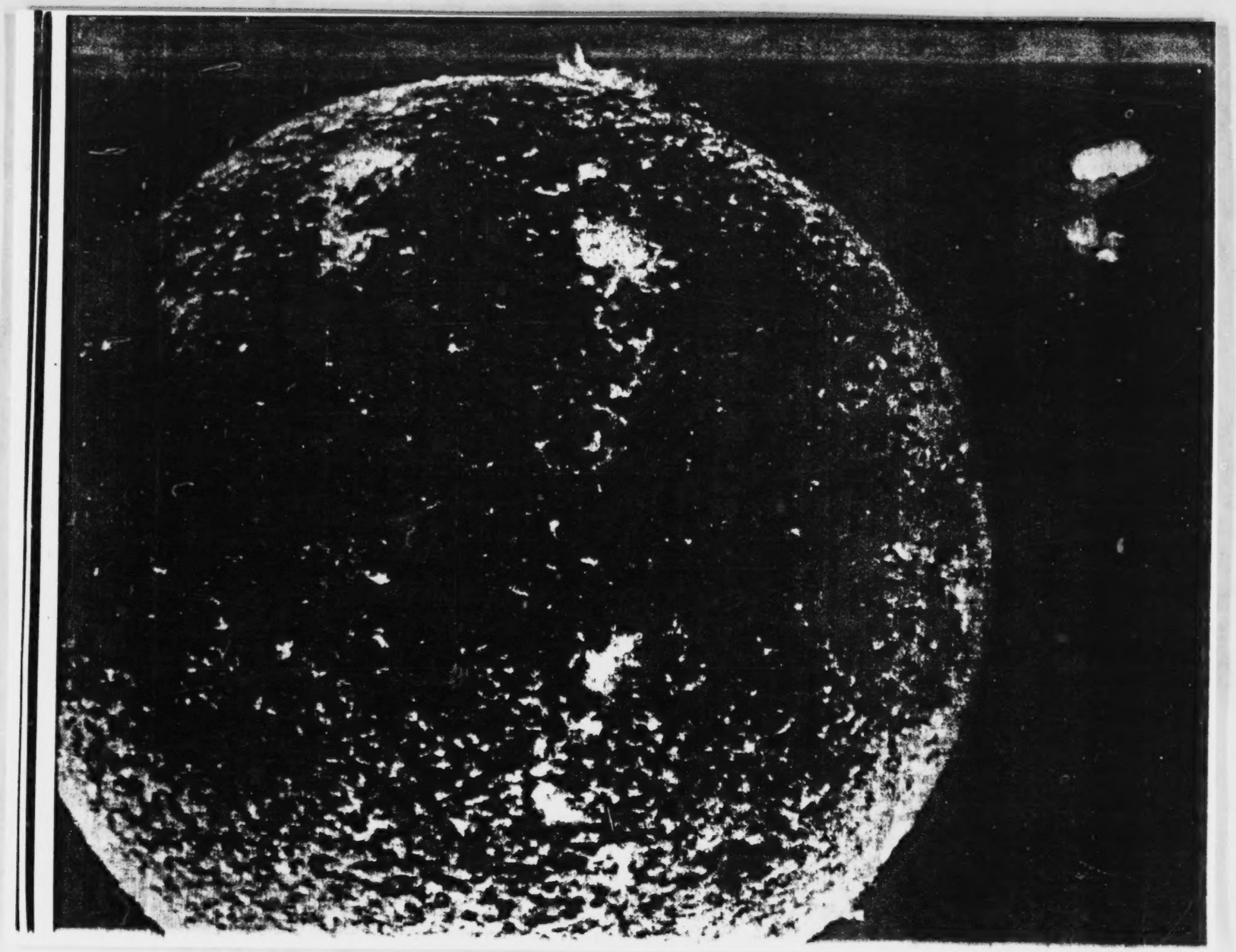


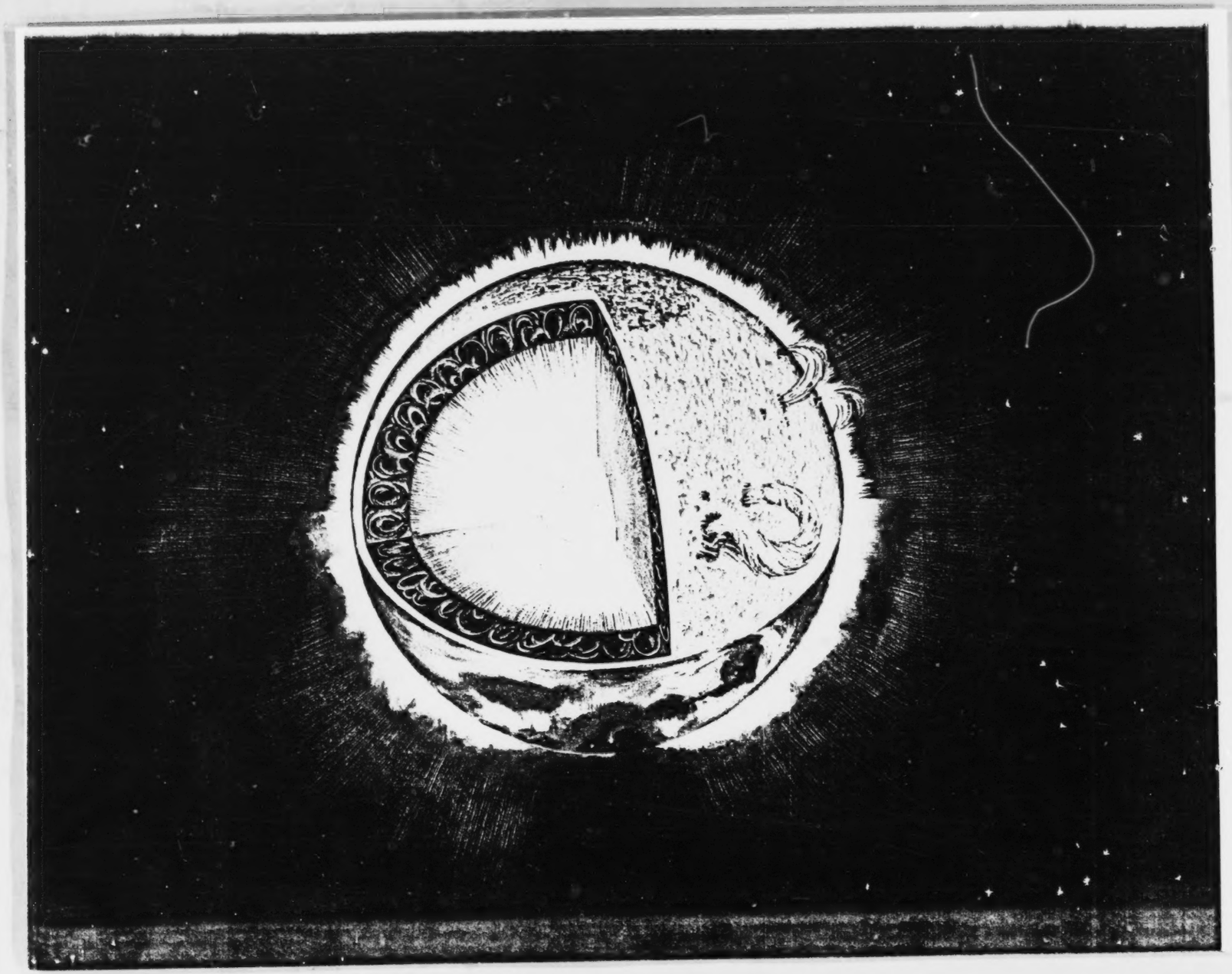
The Sun —Our Nearest Star

The Sun is a star of average mass and luminosity, of middle size and middle age. More than 4.6 billion years ago gravity began to draw together atoms of hydrogen and helium, carbon and oxygen, nitrogen and iron, and bits of heavier material, formed in the exploding cores of older stars, to form a great globe of gas and dust. Later the globe began to glow as pressure mounted deep in the interior until the core ignited and became a seething nuclear furnace.

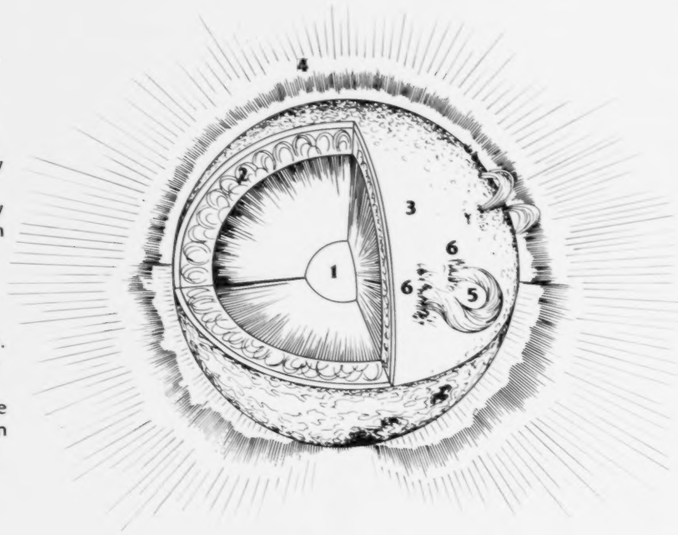
The Sun's core is the nuclear reactor that makes it shine, and our nearest star consumes its fuel at a prodigious rate, about 5 billion kilograms each second. It does that by fusing protons, the nuclei of hydrogen atoms. Each time four protons fuse, the nuclear reaction converts them to a helium nucleus and the hydrogen core gradually becomes a helium core.

Facing page: A great prominence erupts from the limb of the Sun. This prominence triggered a fast-moving and gargantuan disturbance in the corona.

Right: Apollo, the sun god.



Meanwhile, fusion in the core releases energy and that energy works its way gradually outward through the Sun's inner layers until it reaches the photosphere, the visible surface of the Sun and the site of the sunspots discovered by Galileo. The photosphere is also the site of boiling convective motions. Above the photosphere is the chromosphere that is the transition from photosphere to the Sun's outermost region, the corona.



1. Core
2. Convection Zone
3. Photosphere
4. Chromosphere
5. Prominence
6. Sunspots

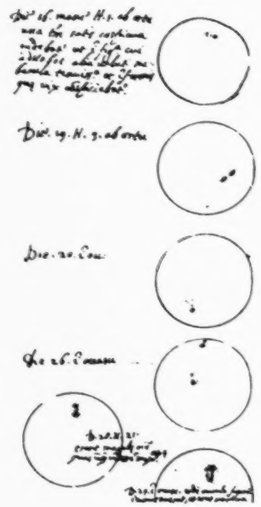
This cutaway shows the Sun's structure. Radiation from the Sun's nuclear core works outward through the convection zone — a spherical shell in which the solar atmosphere turns over. The photosphere is the Sun's visible surface. The solar surface has a mottled appearance (similar to the skin of an orange) containing occasional dark sunspots from which ropelike magnetic fields rise and descend. The lower half of the sphere shows coronal holes while the upper right shows visible-light features of the photosphere.

The Sun's crown is a fine one, a good vacuum by Earth standards, and so diaphanous that we can see it only during eclipses, when the Moon cuts off most of the Sun's light. More energy pours into the corona than it can radiate away and so it must expand into space.

The regions of the Sun that are of primary interest to the scientists of Ulysses are the photosphere and the corona. For they are the regions of the Sun that give rise to most of the physical phenomena that fill the heliosphere.

It was not until the early years of this century that astronomers began to understand the complicated forces at work in the Sun. For example, although Galileo had discovered and observed sunspots on the photosphere during the early 1600s, the nature of sunspots was not understood until 1908 when George Ellery Hale discovered that the Sun is a giant dynamo, a huge electric motor, and sunspots are the sites of intense magnetic fields.

And another 54 years would pass before Mariner 2 made the first direct measurements of a phenomenon that fills all of space within the solar system but had been only theorized before—a great wind that blows from the Sun.



Facing page: The looping structure of a solar prominence shows closed magnetic-field lines above a sunspot group. Material condenses out of the corona and flows downward to the surface.

Right: Sunspots, sites of intense magnetic fields, show clearly on the Sun's photosphere. Sunspots are cooler, and therefore darker, than the surrounding regions.

The Wind From The Sun

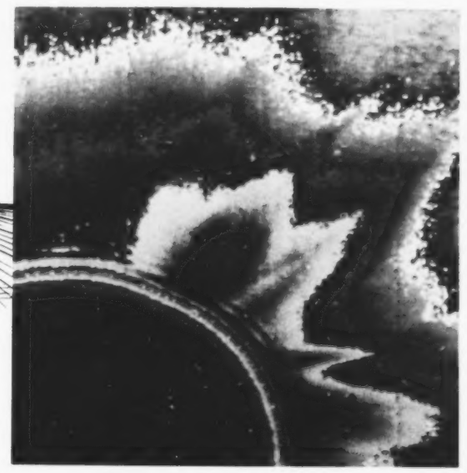
The solar wind is a gale of relatively low-energy atomic particles—protons and electrons that form a hot, magnetized gas, a plasma. Near the Sun's equator the solar wind is exceedingly complex. Particles of high speed overtake those that are slower and the traffic jam can be monumental. And still other particles of higher energy than the solar wind burst from the Sun. The resulting chaos twists and contorts the magnetic field lines in space and the most-energetic particles leap from one traffic lane to another. Any attempt to study the phenomenon becomes as tangled as the magnetic field itself. But scientists believe the solar wind may be less convoluted at high solar latitudes and therefore easier to understand.

When a subject of research becomes too intricate, scientists begin to look for simple examples. Once they can understand the uncomplicated, they believe, they can begin to sort out the more difficult. One major reason why solar physicists look forward with delight to Ulysses is the opportunity to study the solar wind above the Sun's poles, far from the complex equatorial regions. Ulysses will explore regions where the flow of the solar wind and the magnetic fields it carries may provide those less-complicated examples.

Until recently no one knew exactly where in the Sun the solar wind originated. Now scientists believe it comes from great rips in the Sun's corona, called coronal holes.

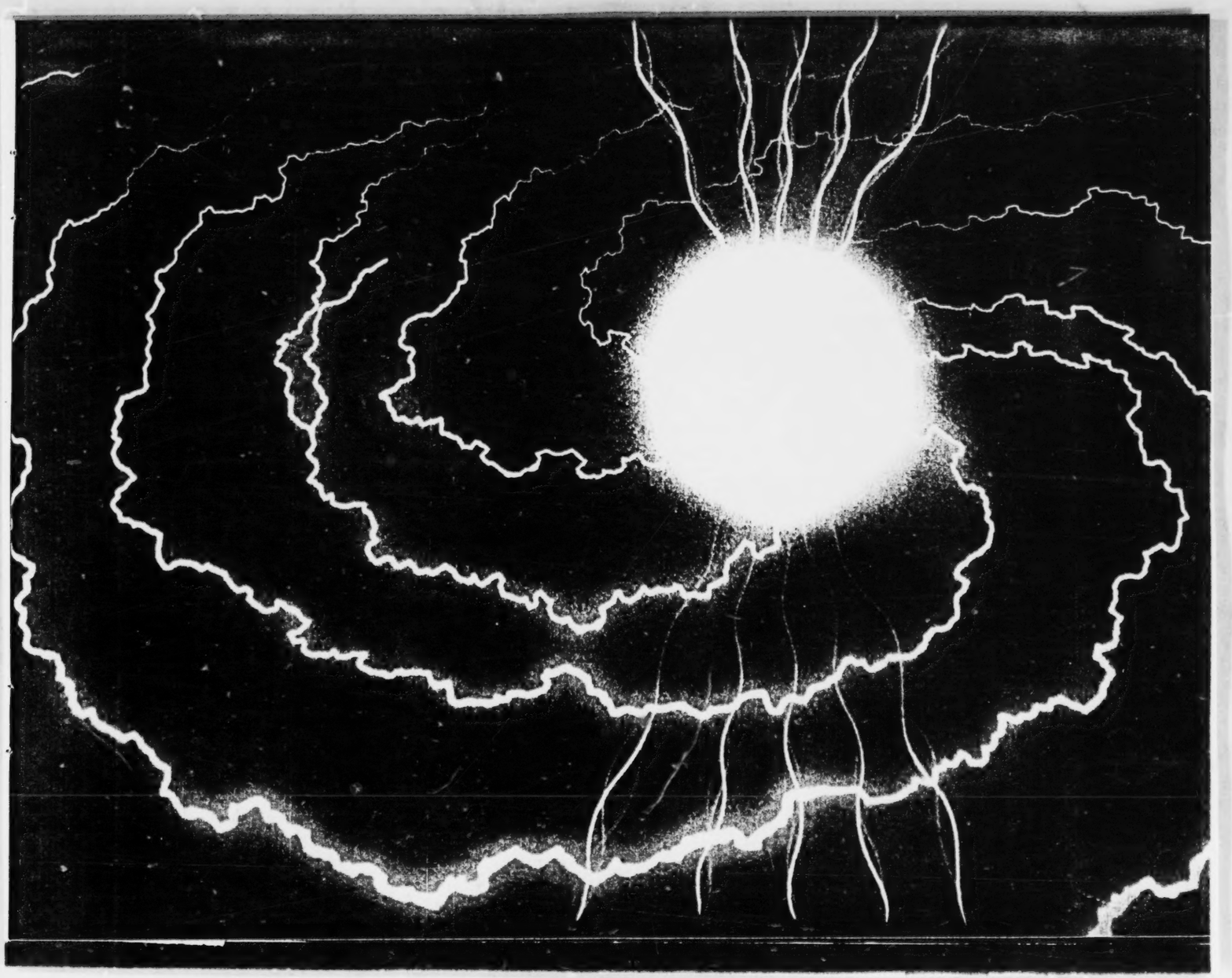
Coronal holes were discovered in 1973 during the flight of Skylab, NASA's early space station. The holes appear to be predominant in the polar regions although they grow toward the equator and then subside poleward again. They appear to be the source for the solar wind's material—low-energy protons and electrons.

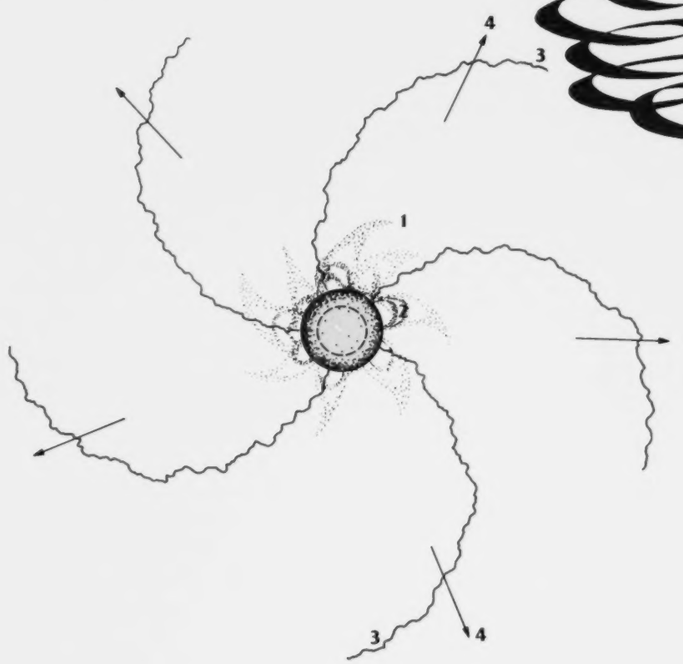
Those particles leave the coronal holes to become the solar wind and they stream out across the heliosphere, creating near the equatorial regions ever-more-complex phenomena. The solar wind's particles have relatively low energy but are bountiful and therefore they dominate the less-dense magnetic-field lines. The solar wind flows straight out in all directions and carries the magnetic field lines with it. To complicate matters though, the Sun rotates and so the magnetic field lines coil up around it like the spring on a tightly wound watch.



Left: False-color image of the corona taken with a coronagraph, an instrument in which a small disk blots out the Sun.

Facing page: Magnetic field lines near the Sun's equator become twisted, while at higher latitudes they are expected to be less complex.





1. Corona
2. Prominence
3. Magnetic Field Lines
4. Solar Wind

In turn, the magnetic field lines carry other particles that have greater energy than those in the solar wind. Each of the high-energy particles has energy of up to millions of electron volts. The highest-energy particles are few in number, so their density is low compared to that of the solar wind. But the magnetic field exerts a force on the energetic particles that causes them, in turn, to corkscrew outward along the tightly wound field lines instead of flowing straight out from the Sun with the lower-energy solar wind.

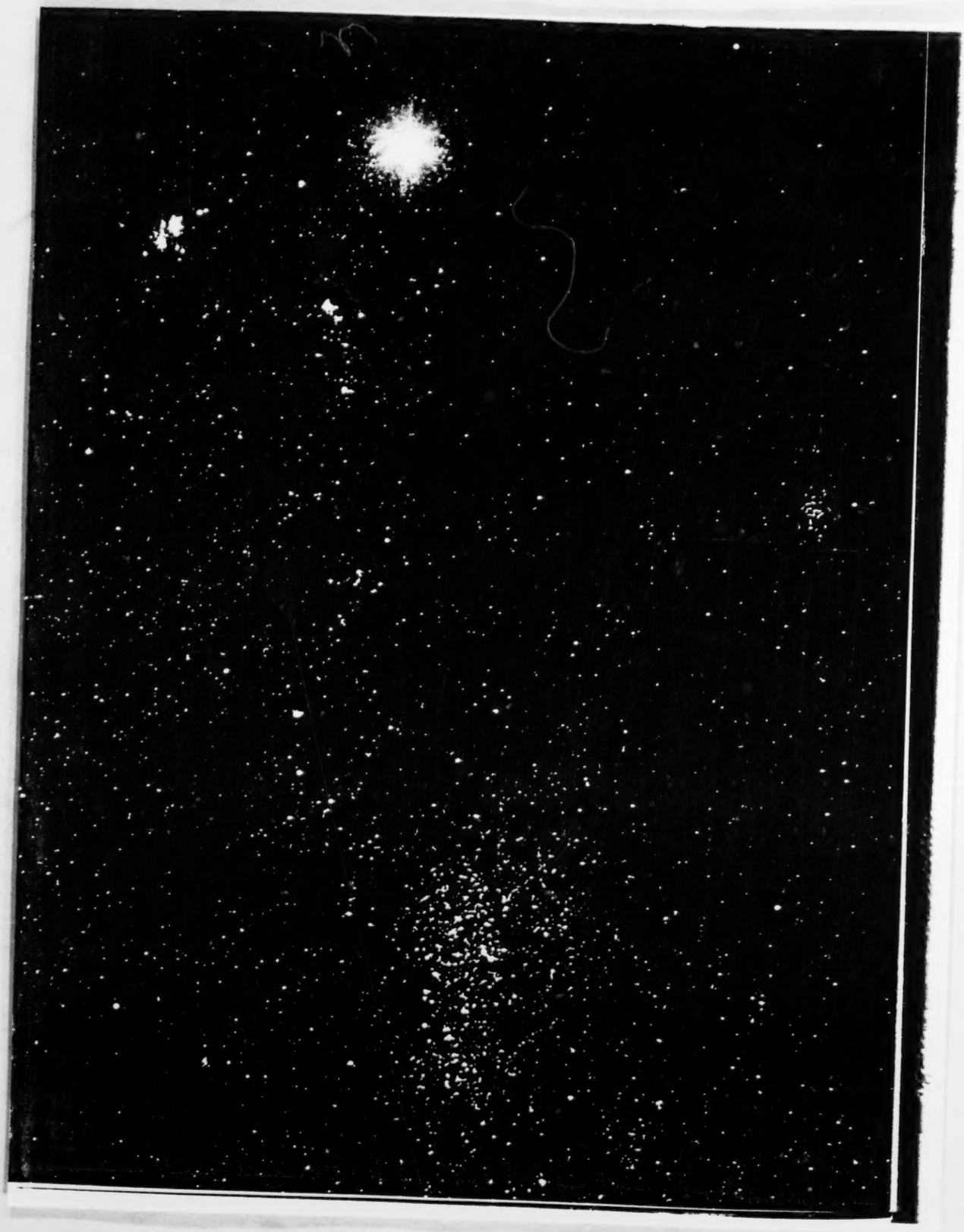
Scientists think that the solar wind that flows from the Sun's poles, unlike the wind from the equator, probably has constant speed. Such straightforward streams of particles are not expected to tangle the magnetic field lines above the poles. The magnetic field lines there may be more open and less complicated than the twisted and tangled paths near the equator. If that is true it would allow scientists to measure and understand many events that cannot be understood near the equator. The major accomplishment would be a clarification of conflicting theories about the heliosphere.

There are complications to Ulysses' tasks, however. The spacecraft will cross over the Sun's poles during a time of maximum storms on the Sun. It may be difficult, therefore, to tell the difference between variations that are caused by solar storms and variations in the structure of the heliosphere as Ulysses passes through them. In particular the differences between polar and equatorial regions may be confused with other variations that occur simply as a result of passing time.

Yet those complications are as nothing compared with scientists' attempts to study cosmic rays from the galaxy that struggle through the solar wind and the Sun's magnetic field into the inner solar system bearing messages from the stars.

Left: This view looking down on a solar pole shows the relationship between magnetic field lines and solar wind.

Facing page: Coronal holes, dark areas in the picture, are regions in the corona where the solar wind originates. X-ray images from Skylab gave physicists their first look at these important phenomena.



Messages from the Stars

Galactic cosmic rays are the nuclei of heavy elements—oxygen, nickel and iron—that flash across interstellar space with incredible energy. Cosmic rays stand apart from all other matter in the universe: These tiny particles possess more energy than can be created in the most advanced accelerators. They almost surely are born in portentous events far away in the galaxy, cataclysmic events like the death of stars.

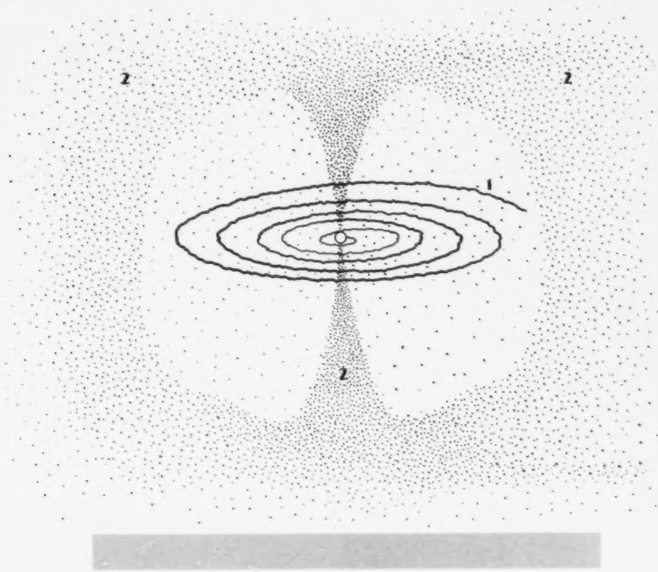
But their messages are useless to scientists if they can't decode them. And they can't decode them if all the symbols in the code have been altered. Cosmic rays that enter the solar system near the Sun's equator are robbed of their energy as they twist and turn and leap along the complex magnetic field lines. They are altered so dramatically by the loss of energy as to be almost unrecognizable.

It is as if some cosmic censor had taken out all the important information by scrambling the letters in the code. Galactic cosmic rays must be detected in their original, pristine condition if their messages are to be understood.

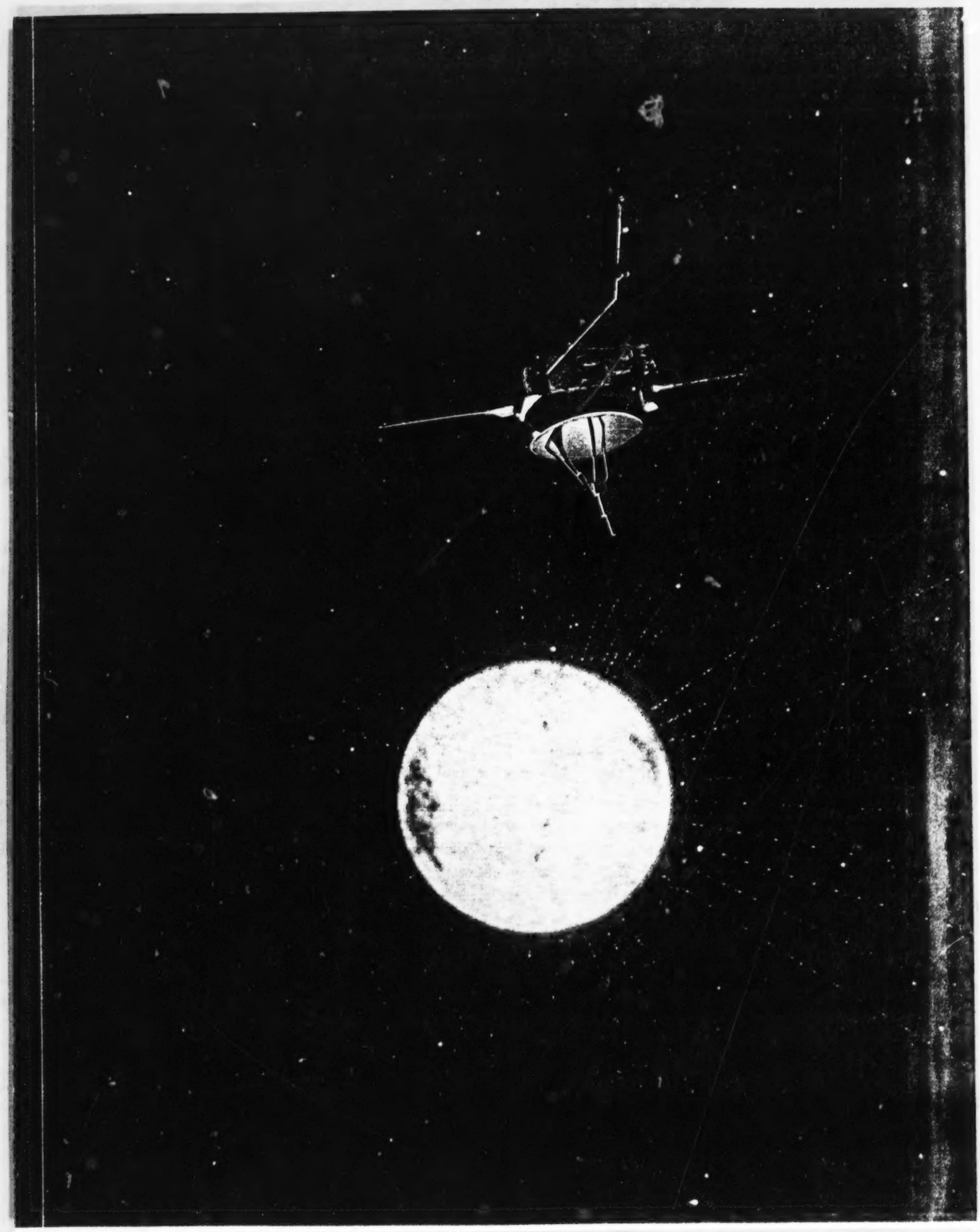
Scientists believe that cosmic rays in or near this condition can be detected over the Sun's poles. It is Ulysses, then, that may detect the particles in their unaltered state and allow an accurate reading of their messages.

Facing page: Light from the stars reaches Earth across the incredible distances of space. But stars also send other messengers, cosmic rays that may tell a very different story.

Right: Cosmic ray particles are represented by dots. Since the solar wind tends to keep the cosmic rays in interstellar space, there are fewer dots in the region dominated by the sun and spiraling magnetic field. However, cosmic rays are thought to have easier access to the heliosphere in the polar regions where the magnetic field is funnel shaped.



1. Magnetic Field Line
2. Cosmic Rays

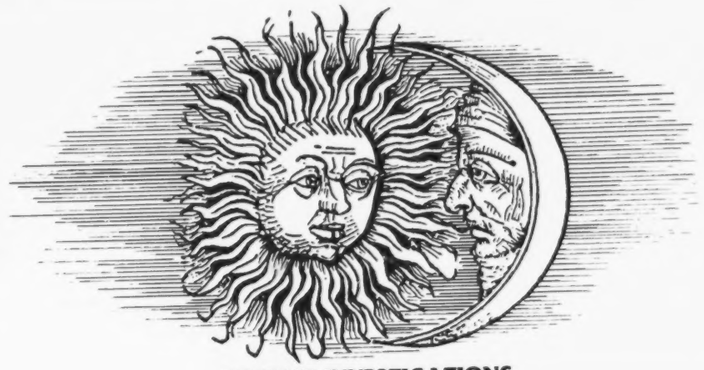


How Ulysses Will Conduct Its Research

The scientific payload on the Ulysses spacecraft consists of nine instruments. The spacecraft radio will conduct a pair of experiments, too, in addition to its primary function of communications with the scientists of many nations and the engineers who control the spacecraft from the Jet Propulsion Laboratory in Pasadena, California.

A solar-wind plasma experiment will detect and analyze particles in the solar wind with the goal of determining variations in the particles from the equator to the poles. The plasma experiment will determine just how the solar wind changes on two fronts: distance from the Sun and distance from the ecliptic plane.

The experiment acts like a space version of a weather station and will measure the solar wind after it leaves the corona.



The Ulysses spacecraft will continuously measure the solar wind streaming from the Sun. The solar wind is thought to fill the entire heliosphere and, after leaving the Sun, to flow radially outward in all directions.

SCIENCE INVESTIGATIONS

Experiment	Principal Investigator
Solar-Wind Plasma	**Samuel J. Bame** Los Alamos National Laboratories
Solar-Wind Ion-Composition Spectrometer	**George Gloeckler** University of Maryland **Johannes Geiss** University of Bern
Magnetic Fields	**Andre Balogh** Imperial College, London
Energetic-Particle Composition	**Erhardt Keppler** Max-Planck-Institut **Helmut Rosenbauer** Max-Planck-Institut
HI-SCALE	**Louis Lanzerotti** Bell Laboratories
Cosmic-Ray and Solar-Particle Investigation	**John Simpson** University of Chicago
Unified Radio and Plasma-Wave	**R.G. Stone** Goddard Space Flight Center
Solar X Rays and Cosmic Gamma Rays	**Kevin Hurley** Centre d'Etude Spatiale des Rayonnements **Michael Sommer** Max-Planck-Institut
Cosmic Dust	**Eberhard Grün** Max-Planck-Institut
Coronal Sounding	**Hans Volland** Bonn University
Gravitational Waves	**Bruno Bertotti** University of Pavia

The plasma instrument will measure local changes in the number of particles and in their energy as the solar wind blows past Ulysses while it travels along its flight path.

Scientists know little about the speed and density, direction and temperature of plasmas in the solar wind at high latitudes. If the solar wind at the poles originates from coronal holes there, then it would be free of many of the complications associated with coronal holes near the equator. Near the equator, when quiet regions of the rotating corona pass a given location, low-energy particles stream forth. When the coronal holes move past the same site, high-speed particles pour out and overtake the slower low-energy particles. Thus scientists who have measured the solar wind are confused by the alternating slow and fast streams. At the poles, however, effects associated with the collisions between slow and fast streams may be absent. The plasma instrument should be able to measure how the properties of the solar wind differ between low and high latitudes and should be able to trace the solar wind back to its place of origin more easily at the poles than at the equator. The solar-wind plasma instrument will observe particles in the energy range from 1 electron volt to 35,000 electron volts.

Dr. Samuel J. Bame of the Los Alamos National Laboratory is principal investigator.

■ A solar-wind ion-composition spectrometer is expected to provide unique information on conditions and processes in that region of the corona where the solar wind is accelerated. The instrument will study composition and temperatures of heavy ions in the solar wind. The solar wind contains electrons, protons, alpha particles (the nuclei of helium atoms) and heavy ions such as oxygen, silicon and iron. The relative amounts of all those materials are not well understood but are expected to differ under differing local conditions and because of changes in the corona where the materials formed. An important measure is their degree of ionization, a result of differing temperatures at the source.

Temperatures in the corona vary depending on the state of the magnetic fields in the photosphere beneath. High temperatures create mixtures of ions that are different at different heights. Each mixture is then locked into the solar wind; it does not change as it leaves the corona. The solar-wind ion-composition spectrometer measures the mixtures and temperatures of ions as they strike the spacecraft. Once scientists have determined those temperatures they should be able to find the location in the corona of the sources of the solar wind, the coronal heating processes and the extent and causes of variations in composition of the Sun's atmosphere.

Dr. George Gloeckler of the University of Maryland and Dr. Johannes Geiss of the University of Bern, Switzerland, are coprincipal investigators.

■ A pair of magnetometers, each of which is suited to a different purpose, is carried aboard Ulysses. Like a spaceborne Magellan or Cook they will map the heliospheric magnetic field as the spacecraft travels through it. Use of the pair of magnetometers will allow the investigators to monitor changes in the magnetic field at the spacecraft. A vector-helium magnetometer will measure slight fields, while near Jupiter a flux-gate magnetometer will measure the planet's intense magnetic field.

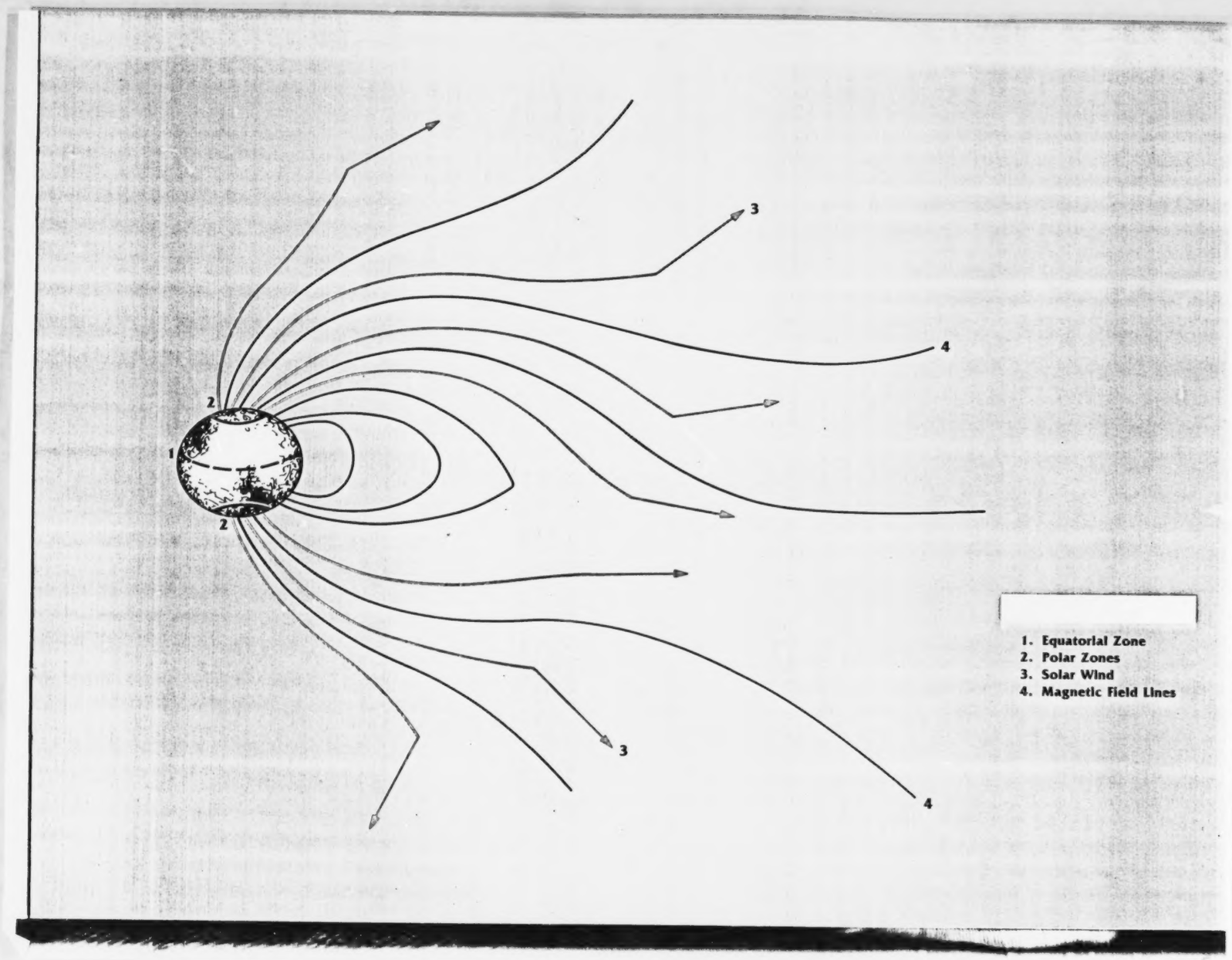
Still more important, the two magnetometers will measure the magnetic fields above the Sun's poles.

Since the magnetic field lines are borne outward across space on the wings of the solar wind, knowledge of the shape and structure of the field lines at high latitudes would be important to those who are studying the solar wind and the energetic charged particles.

If the solar wind is simple above the poles, it should be possible to infer the character of the magnetic fields at the Sun's polar caps. Very little is known about the fields there (such as their strength) because it is nearly impossible to observe them from the lower latitudes where all earlier spacecraft have flown.

The magnetometer team is interested in particle streams riding the solar wind outward from the Sun. Do the magnetic field lines near the poles cause clouds of plasma to act differently than they do nearer the equator? For example, the field lines at the poles are expected to arrange themselves nearly parallel to the flow of the solar wind, so the plasma clouds are not kept distinct and separate (as they are at the equator where the field lines are perpendicular to the flow).

While some of the Sun's magnetic field lines are closed, most are borne outward on the solar wind.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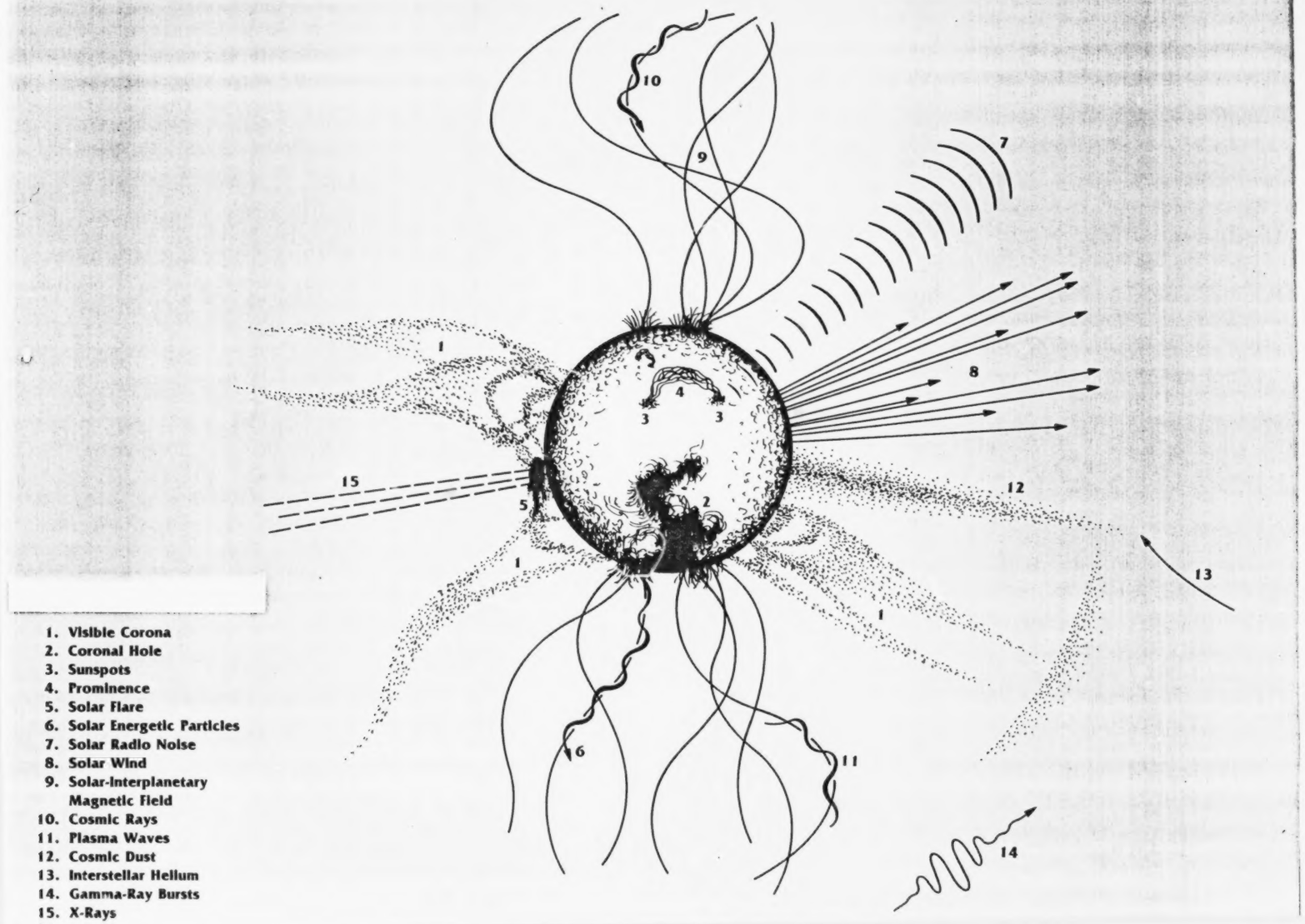
1. Equatorial Zone
2. Polar Zones
3. Solar Wind
4. Magnetic Field Lines



1. Visible Corona
2. Coronal Hole
3. Sunspots
4. Prominence
5. Solar Flare
6. Solar Energetic Particles
7. Solar Radio Noise
8. Solar Wind
9. Solar-Interplanetary Magnetic Field
10. Cosmic Rays
11. Plasma Waves
12. Cosmic Dust
13. Interstellar Helium
14. Gamma-Ray Bursts
15. X-Rays

Dr. Andre Balogh of Imperial College, London, is the principal investigator on the magnetometer experiment and has provided the flux-gate magnetometer. Dr. Edward J. Smith of Jet Propulsion Laboratory, the U.S. project scientist and a coinvestigator on the magnetic-fields team, provided the vector-helium magnetometer.

■ An instrument called the energetic-particle-composition experiment has two tasks: to detect and measure ions in the solar wind that are in the medium-energy range and to detect helium atoms entering the solar system from interstellar space.

While the high temperatures in the Sun's corona accelerate the solar wind's low-energy particles, the medium- and higher-energy particles achieve energies that are much too great to have been caused by such relatively simple heating processes. No one knows what processes cause the acceleration of the medium- and high-energy particles. In addition, once the particles with medium and high energy are accelerated, they appear to be stored temporarily in the corona, to be released sometime later along the magnetic field lines. (Physicists observe solar flares where the particles originate but they do not see any of the particles arrive at Earth at the time they should.) The structures in the corona where the storage and acceleration processes are believed to occur are apt to extend to high solar latitudes during the period of maximum solar activity—just as Ulysses is flying over the Sun's poles. The energetic-particle instrument will detect the particles of medium energy in an effort to understand the processes of the coronal-storage phenomenon and how that storage depends on the particles' energy. The instrument will also study how solar latitude affects the paths along which the particles move through the heliosphere.

The other experiment that is allied with the energetic-particle detector will search for neutral helium—atoms that have no net electric charge—coming from the Milky Way. Interstellar hydrogen and helium gas exists throughout the Milky Way, perhaps as both a remnant and a source of the star-formation process. The solar system moves through that gas as we orbit the center of the galaxy.

Neutral helium is extremely difficult to detect. However, the hydrogen is even more difficult to see in the inner heliosphere since a helium atom is four times more massive and holds onto its electrons with a stronger force. Since it has no electric charge to trap it in the Sun's magnetic field lines, the helium falls directly in toward the Sun, drawn there by gravity. The helium atoms therefore penetrate deeper into the solar system (to about the Earth's distance) than the hydrogen atoms before they are ionized and carried outward again by the solar wind.

The interstellar helium can't be detected until the Sun's gravity gives it enough speed and that doesn't occur until it is between 1.2 and 1 astronomical units from the Sun. So the helium-detection portion of the experiment will operate only during the first 70 to 100 days of the flight.

Dr. Erhardt Keppler of the Max-Planck-Institut für Aeronomie in West Germany is principal investigator of the energetic-particle detection experiment and Dr. Helmut Rosenbauer, also of the Max-Planck-Institute für Aeronomie, is principal investigator of the interstellar neutral helium experiment.

■ An instrument called HI-SCALE will study interplanetary ions and electrons with a wide range of energies, from high-energy particles in the solar wind to particles with *extremely* high energies—the Sun's equivalent of cosmic rays. Scientists hope to understand the mechanisms that release solar-flare particles and the dynamic phenomena that are associated with the solar cycle's maximum activity.

The instrument will use the flow of high-energy particles from eruptive processes on the Sun to study structural changes in the corona and in the magnetic field lines. (They can do that because the Sun's high-energy particles travel paths that reveal the field lines carried by the solar wind.) The structures are expected to change as the spacecraft flies ever-farther from the ecliptic plane. Interactions between the particles and waves that move through the solar wind also may be responsible for the energy imparted to particles in the solar wind and therefore could explain their speeds.

This composite of the Sun's most intriguing and mysterious phenomena summarizes the motivation for research through the experiments flown on the Ulysses mission.

Scientists on the HI-SCALE team will also try to measure the composition of low-energy nuclei from the Sun both in the ecliptic plane and at high solar latitudes since those nuclei should give information on the Sun's composition. The instrument should also provide clues about how the masses of individual particles influence their acceleration due to electromagnetic forces.

HI-SCALE is an acronym for Heliospheric Instrument for Spectral, Composition and Anisotropy at Low Energies.

Dr. Louis Lanzerotti of Bell Laboratories is principal investigator.

■ A cosmic-ray and solar-particle investigation will search for particles inbound from other regions in the Milky Way galaxy. Team members hope to sample these objects in near-pristine condition, unaltered by the Sun's magnetic field lines near the ecliptic plane.

Its specific goals include an understanding of acceleration and movement of charged particles in interplanetary space—primarily the cosmic rays that originate beyond the solar system: Most important, what are cosmic rays like before they enter the solar system? How do galactic cosmic rays change?

And from measurements of particles not accessible in the plane of the ecliptic, how and where do the cosmic rays originate, what forces act on them and how do they travel through the Milky Way?

The experiment can distinguish between the different elements present in cosmic rays. It can identify such heavy particles as hydrogen nuclei, helium nuclei, oxygen and nitrogen. The physicists on this team also hope to determine individual isotopes of each element, which would tell them about how the cosmic rays were created.

Dr. John Simpson of the University of Chicago's Enrico Fermi Institute is principal investigator.

■ The Sun is a mighty broadcaster of radio signals that move across the solar system at the speed of light, and high-energy electrons that move outward as the result of solar eruptions also produce low-frequency waves of energy.

Ulysses' unified radio and plasma-wave experiment has two objectives: The first is to determine the direction and polarization of radio sources flowing outward from the Sun and the second is a detailed study of waves in the solar wind — waves associated with local variations in the properties of clouds of plasma that move through the interplanetary medium.

The unified radio and plasma-wave experiment is both a remote-sensing and a local-measurement instrument. It senses the longer radio frequencies that originate at great distances and the shorter plasma-wave frequencies as they move past the spacecraft.

Scientists on this team, along with colleagues on others, are seeking to understand the basic physics of plasmas—clouds of particles that have lost one or more of their electrons and thus have been electrically charged. Electrons that move with the plasma cloud follow magnetic field lines of the heliosphere, emitting electromagnetic waves. Both ions and electrons in streams of plasma interact with the solar wind to create plasma waves. Scientists want to know three things about the waves: What is their source? How do they interact with the solar wind? And how do various kinds of waves depend on the medium through which they move?

Dr. R.G. Stone of NASA's Goddard Space Flight Center is principal investigator.

■ In 1959 scientists discovered that solar flares emit X-rays; in 1973 they discovered gamma rays bursting into the solar system intermittently from interstellar space; and in 1983 X-rays were discovered coming from Jupiter.

The solar X-rays and cosmic gamma-ray bursts experiment is intended to provide new data on those perplexing high-energy particles.

The solar-flare X-ray portion of the experiment will work in conjunction with spacecraft that are flying in the ecliptic. The goal is to determine how the intensity of the bursts varies with their direction.

Observations of X-rays from the Sun by Ulysses and those by spacecraft in the ecliptic such as Galileo, which will be enroute to Jupiter, will help to determine the movement of electrons within intense solar-flare magnetic fields on the Sun. The physicists of Ulysses also want to measure how the energy of the solar X-rays differs as the flares emit them in different directions.

Little is known about any of these phenomena and least is known about gamma rays; they do not come from the Sun but from elsewhere in the galaxy.

Scientists have problems explaining the perplexing gamma-ray observations: How are the gamma rays produced? What objects are responsible for the extremely high-energy gamma rays? Supernovas? Black holes? The physicists have not yet been able to triangulate gamma-ray bursts closely enough to pinpoint their sources.

Gamma-ray bursts are fairly rare events compared with other phenomena that Ulysses will study but during its mission Ulysses is expected to sense more than 50 a year as they pass through the solar system.

Dr. Kevin Hurley of the Centre d'Etude Spatiale des Rayonnements, France, and Dr. Michael Sommer of the Max-Planck-Institut für Extraterrestrische Physik, West Germany, are coprincipal investigators.

■ One Ulysses experiment will measure the dust particles that move through the solar system.

The dust probably originated in several different ways: Some may be left over from the creation of the solar system. Some has undoubtedly been left behind by comets streaking past the Sun. Still other dust may have come from collisions of great boulders in the asteroid belt. Finally some probably comes into the solar system from interstellar space.

Dust particles in space are extremely tiny, about the size of the particles in cigarette smoke. Two basic forces act on the dust particles at the same time: gravity and solar radiation. Depending on their sizes, the individual particles can be drawn inward toward the Sun by gravity or forced outward by the pressure of solar radiation. Still other dust particles are just passing through, on their way from interstellar space through the solar system and out again.

The Ulysses dust experiment aims to measure the speed and flight direction of particles, it will measure the electric charges they acquire as they fly through the solar wind and it will attempt to determine if the dust exists in greater amounts at higher latitudes than in the ecliptic plane.

Dr. Eberhard Grün of the Max-Planck-Institut für Kernphysik in West Germany is the principal investigator.

■ Twice during the Ulysses mission the spacecraft and the Earth will be on opposite sides of the Sun. The first such orientation will occur about 10 months after launch and the second about one year later. During those opportunities scientists will use radio signals to and from Ulysses to measure the density of electrons along the path the radio signals take from Earth to the spacecraft and back as they pass the Sun.

Since interplanetary space is not a perfect vacuum, the radio signals' speed will be slightly affected by the material they pass through. Therefore the frequency of the signals will change slightly as they pass through the Sun's corona. Part of that shift is caused by relative motions of the spacecraft and Earth. Yet another part is caused by the electrons in the signals' path. In addition irregularities in electron density make the radio waves scintillate or twinkle just as starlight does and that scintillation is a measure of the number of electrons near the corona.

The unique thing about Ulysses' measurements is that they will count the electrons as they stream from a region of the Sun that has never been seen before —high solar latitudes.

Dr. Hans Volland of Bonn University is the principal investigator.

■ Ulysses may provide evidence in support of Albert Einstein's theory of gravitation (the Theory of General Relativity). Relativity predicts the presence of gravitational waves. They are ripples in Einstein's space-time caused by matter or mass in motion. Particularly strong waves could be produced by cataclysmic events involving vast amounts of matter in quasars and the centers of exploding galaxies. An example of such an event would be the collapse into a black hole of matter equivalent to 100 million times the Sun's mass. Current astronomical observations appear to lend credence to the existence of such objects in the centers of galaxies. Gravitational waves would travel out from such events through space at the speed of light and disturb the position of any object that they pass.

Thus gravitational waves are similar in many ways to radio waves: An essential difference is that radio waves are created by moving electrical charges while gravitational waves are created by moving masses. And radio waves are many times stronger than gravitational waves.

Gravitational waves would cause extremely tiny changes in a local gravity field and would be extraordinarily difficult to detect. Although experiments are under way to search for them, the consensus is that none has been detected as yet.

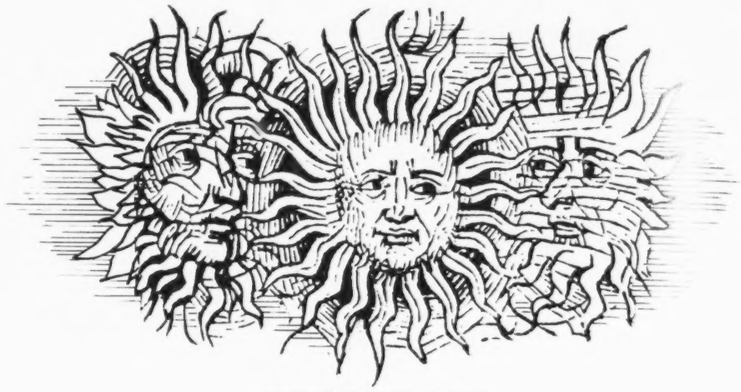
If a gravitational wave were to pass through the solar system while Ulysses is out at the distance of Jupiter, the wave would alter the distance between Ulysses and the Deep Space Network antenna that is tracking it by less than one centimeter across 746 million kilometers. Thus those changes in distance cannot be measured directly.

However, by using the Deep Space Network's hydrogen-maser clocks, scientists can measure tiny changes—called Doppler shifts—in the frequency of radio signals making the round-trip between Earth antennas and the spacecraft. Those minute changes are measured against the DSN's extremely accurate clocks.

Einstein's theory of gravitation predicts that a tiny fractional frequency shift will occur if a gravitational wave passes through the solar system while Ulysses is near Jupiter. Such a minute change, a decimal followed by 14 zeroes and a 3, would be detectable by the Deep Space Network's hydrogen-maser clocks.

Professor Bruno Bertotti of the University of Pavia, Italy, is principal investigator.

■ Finally a team of interdisciplinary scientists who are not attached to any of the experiment teams has perhaps the most difficult task of all: They will work to construct a complete and coherent model of the heliosphere from the data furnished by most of the instruments.



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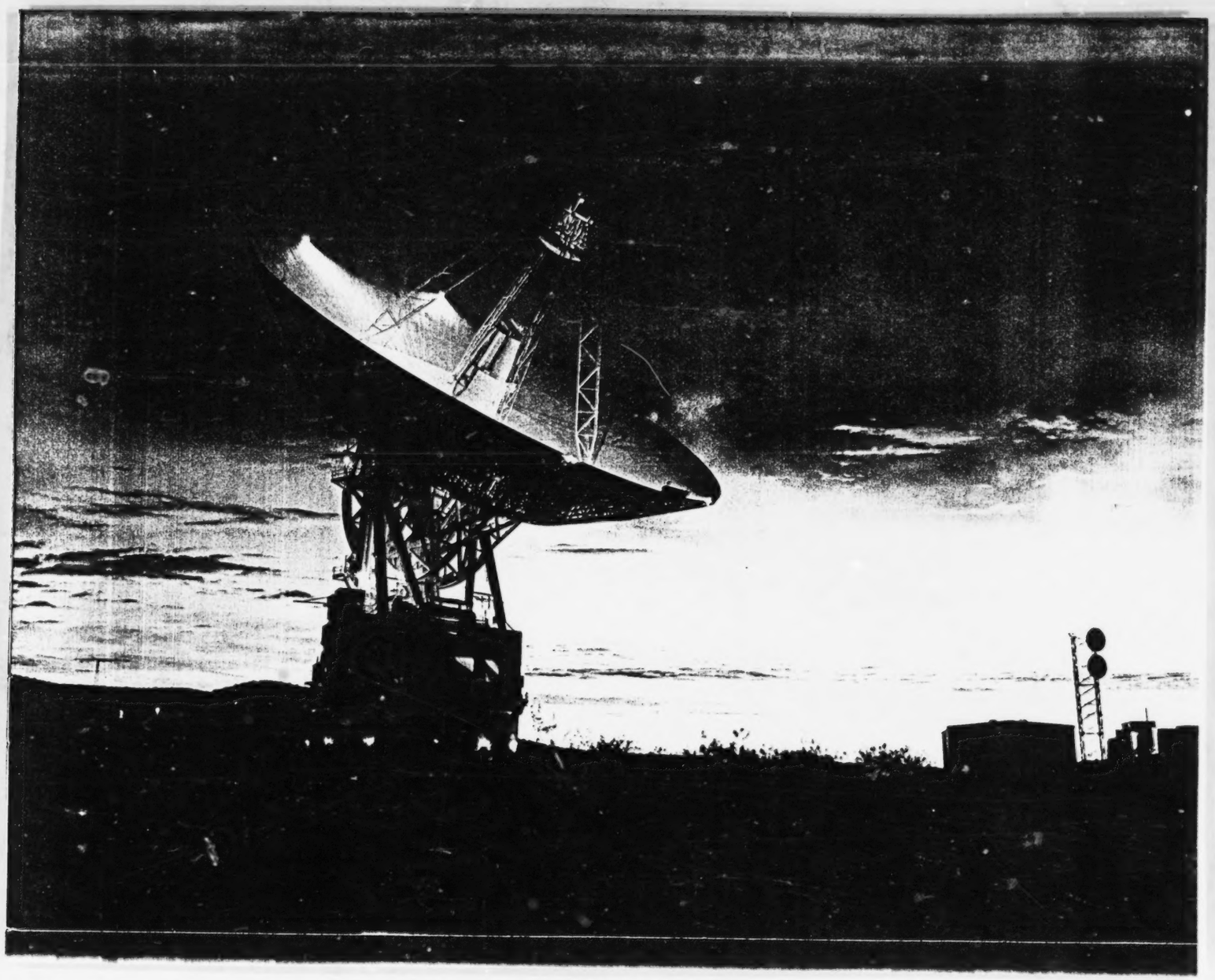
European Space Agency

The European Space Agency's share of the Ulysses project is headquartered at Noordwijk, The Netherlands, and is managed by Derek Eaton, Project Manager; Klaus-Peter Wenzel is the Project Scientist.

The 64-meter (210-foot) antenna at Goldstone, California, will receive the weak radio signals that will make it possible to track Ulysses and collect data for scientists here on Earth.



Facing page: This great solar eruption is typical of the solar phenomena that Ulysses will study during its long mission to observe the poles of the Sun.

How Ulysses Won Its Name

Until 1984, the Ulysses project was called the International Solar Polar Mission. The name described the mission's objectives but project officials believed it brought little romance to an undertaking they considered exciting. So they held a contest to choose a new name. Prof. Bruno Bertotti, principal investigator of the gravitational-wave experiment, suggested "Ulysses" and cited the 26th Canto of Dante's Inferno: "... referring not only to the adventurous trip of this mythological Greek hero after Troy's war ... but rather to a most remarkable late Medieval tradition in which the spirit and the driving motives of all human explorations of unknown regions are forcefully presented. Dante's story says that Ulysses, after his return home to his beloved wife, Penelope, and to his kingdom in Ithaca, became bored with everyday life and the troublesome duties of a king: with his old shipmates he decided to start for a new journey to explore that part of the world which lay beyond Gibraltar, at that time completely unknown and unexplored ... As Dante says, there is indeed a 'mondo sanza gente,' an 'uninhabited world beyond the Sun' where there are no planets, no possibility of life, no familiar features." According to Dante, Ulysses' crew mutinied out of fear and he exhorted them to continue "To follow after knowledge and excellence."

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